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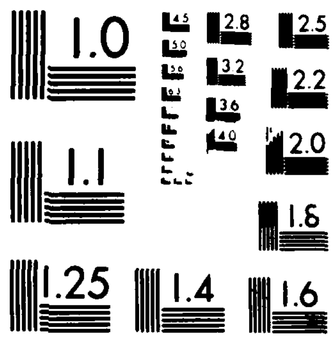

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LEG AND FOREARM MUSCLE POWER CHANGES ASSOCIATED WITH TWO TYPES OF UNDERWATER EXPOSURI

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TECHNICAL REVIEW AND APPROVAL

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The experiments reported herein were conducted according to the principles set forth in the current edition of the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

This technical report has been reviewed by the NMRI scientific and public affairs staff and is approved for publication. It is releasable to the National Technical Information Service where it will be available to the general public, including foreign nations.

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Forearm muscle strength and leg muscle power were studied in 26 Explosive Ordnance Disposal (EOD) and 5 Special Warfare Swimmer Delivery Vehicle (SDV) divers. Control tests were done on non-diving days. Post-dive testing of the EOD divers occurred after a scuba swim in a pool with water at 24 °C. The divers wore no thermal protection. SDV diver testing was done after 2 hr swimmer delivery vehicle training dives in 2 °C water. The divers wore wet suits for the dive, but not for testing. Body temperature measurements were made before and after each dive. An ischemic handgrip test measured developed force at a contraction rate of 1 per sec for a period of 60 sec. The Wingate anaerobic test measured leg muscle power during 30 sec of high intensity exercise on a bicycle ergometer. The results indicated that the EOD divers had a faster rate of body heat loss during their pool swim than did the SDV divers during their open water dives. Handgrip force was noticeably reduced in EOD divers post-dive, while no significant change was observed following SDV dives. The rate of forearm muscle fatigue was largely unaffected by either

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the pool swim or the cold water exposure. Peak leg muscle power was lower post-dive in the EOD group, but unchanged in the SDV group. This could be explained partially by the moderate leg exercise during the EOD swim, whereas the SDV divers had minimal leg exercise during their dives. The average leg power was reduced post-dive in both groups, suggesting that both dive exposures lessened the ability to sustain power. This study indicates that muscle performance is reduced after underwater exposures that mimic operational diving. The nature of the task performed during a dive in conjunction with water temperature, determines the extent to which muscle power or fatigue will be affected. Keywords:

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDICES

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INTRODUCTION

Free swimming divers rely on leg power for propulsion to and from their objective. Studies have shown that the power generated by the leg muscles correlates well with athletic performance in sports like cycling and running (1,2,3). Operational diving, especially for Special Warfare and Explosive Ordinance duties, often requires the diver to perform leg work under a wide range of water temperatures and with various degrees of passive thermal protection. One might then hypothesize that leg power in these divers may also relate importantly to mission success.

While leg power can be of importance in reaching the objective, forearm muscle force can be of equal importance in the successful completion of the task once the target is reached.

Our previous work during open water training operations has shown that cold water lessens work performance capability in combat swimmers (4). For example, maximum forearm grip strength is reduced by about 10% after 1-2 h exposure to 2 °C water. These findings are in general agreement with controlled laboratory studies (5).

The present study was designed to assess leg and forearm muscle power before and after underwater exposures that mimic operational dives. Anaerobic testing of these muscle groups was performed on one set of divers after a scuba swim in a pool, and on a separate set of divers after cold water training dives.

Comparisons were made between results obtained on non-diving vs diving days and between pool temperature vs cold open water diving, with special reference to the type of work performed during each dive.

The Wingate anaerobic test was used to assess leg muscle power and fatigue during a 30 sec high intensity effort on a bicycle ergometer (6). An ischemic handgrip test measured forearm muscle force anaerobically during temporary

occlusion of forearm blood flow (7). Both tests are designed to evaluate skeletal muscle performance in terms of the intrinsic capacity of the muscle to generate and maintain power. They were selected in order to assess the inherent work capability of forearm or leg muscles without a significant dependence on aerobic capacity or blood flow.

METHODS

The first group consisted of 26 EOD divers undergoing scuba training swims in a pool setting. The second group consisted of 5 Special Warfare divers conducting open water training sessions with the SDV. All subjects were briefed on the exercise protocol and gave informed consent. All testing protocols were reviewed and approved by the NMRI Human Use Committee. The physical characteristics of each group are presented in Appendix A.

Control exercise data were obtained on the EOD divers on a non-diving day, with test exercise data obtained two days later after the divers had completed an open-circuit scuba swim on air. Scuba dives were conducted in a pool with maximum depth of 7.3 msw (24 fsw) and a water temperature of 24.4 °C (76 °F). Divers wore only swim trunks and a cotton shirt. The scuba swim was planned to be about 1800 m long (about 2000 yd), with surfacing criteria being either completion of the distance or a tank pressure of 500 psig. In actuality, the swim lasted 53 ± 1 min at an average swimming velocity of 35 ± 1 m/min (115 ± 3 ft/min).

The SDV divers were tested on 3 successive days, the first and third being dive days and the second being the non-diving control day. Training dives were conducted in open water at a temperature of 2 °C (36 °F). Divers wore full neoprene wet suits (0.25 in thickness). Dive times averaged 119 ± 7 min at a maximum depth of 7.6 msw (25 fsw). Breathing gas was either air or nitrox with a PO_2 of 0.7 ATA.

ISCHEMIC HANDGRIP TEST

The ischemic handgrip test, designed to examine forearm muscle force during temporary occlusion of arterial blood flow, assesses the ability of the muscle to perform work anaerobically. A blood pressure cuff was applied to the upper arm and inflated to a pressure of 200 mm Hg to occlude arterial flow. The subject then squeezed a handgrip dynamometer with maximum force at a rate of 1 contraction per sec for a period of 60 sec. The force was recorded on a chart recorder for later analysis of peak force of each contraction over the duration of the test.

Handgrip force was measured in both arms of all divers on the non-dive day and as soon as possible after each dive. Post-dive testing was done between 3-30 min after completion of the EOD scuba swim and 10-20 min after completion of the SDV training dive.

The handgrip dynamometer was calibrated before each testing session by suspending a known weight from the hand assembly and recording the force on a chart recorder. Records were analyzed with the aid of a computer. Averages of the handgrip force were made over each 15 sec segment of the test. Each force measurement was further expressed as a percent of the value obtained for the first contraction, with data also presented as segmental time averages.

LEG POWER TEST

The Wingate anaerobic test was conducted with a mechanical bicycle ergometer. The test consisted of 2 min of pedalling of the bike with no tension on the flywheel, followed by 30 sec of pedalling as fast as possible with the bike tension set to 0.075 gm/kg body weight. Revolutions of the bike flywheel were sensed by a photoelectric detector which computed revolutions per min (rpm), and then registered them on a chart recorder. Calibration of the rpm circuit was done with an electronic strobe over the range of 0-800 rpm.

Bike rpm records were analyzed with the aid of a computer which computed power according to bike tension and rpm. Total work was obtained from the temporal summation of power. Data were analyzed in terms of the peak power generated within the first 5 sec, power at 30 sec, and the total work done over 30 sec.

BODY TEMPERATURE CHANGES

To assess the degree of thermal stress imposed by both diving situations, core and skin temperatures were obtained before and after the dives in each group. Rectal (T_{rec}), right forearm skin (T_{arm}), and left lateral thigh (T_{thi}) temperatures were recorded. An estimate of body heat content was made using the following approximation:

$$\text{Body Heat} = 0.83 \times \text{wt} \times [0.66(T_{rec}) + 0.34((T_{arm}+T_{thi})/2)]$$

where 0.83 is body specific heat (kcal/kg/°C) and body weight (wt) is expressed in kg. The estimate of body heat loss was then determined as the difference between pre-dive and post-dive body heat values. Comparisons between EOD and SDV heat losses were done by normalizing heat loss to actual time of immersion.

RESULTS

BODY HEAT LOSS

Appendix B presents the changes in body temperature and the net loss of body heat that occurred with the two dive profiles. Although the EOD dives were conducted in warmer water, albeit with no passive thermal protection, the rate of body heat loss was significantly greater than that measured after the SDV dives (far right panel of the table).

HANDGRIP STRENGTH

Appendix C presents the segmentally averaged ischemic handgrip data for both

groups. There were no significant differences between right and left hand values of either dive group.

The EOD pool dives resulted in uniformly lower post-dive handgrip values over each time segment. Figure 1 presents the percent change in force relative to the first contraction for both hands under post-dive and non-dive conditions. Although actual force values were lower post-dive, the figure indicates that the rate of fatigue (decline in force with time) was not affected by prior exposure to a scuba swim.

Handgrip force data for the SDV divers, presented in Appendix C, revealed no significant differences between non-dive and post-dive values. This was due, in part, to larger subject variability in this small sample size. Figure 2 indicates that the rate of forearm fatigue was largely unaffected by the open water dives. A comparison between figures 1 and 2 illustrated that the rate of fatigue for SDV divers appeared to be somewhat greater than for the EOD divers, both with non-dive and post-dive data. The small number of SDV subjects precluded a rigorous statistical analysis of this observation.

LEG POWER

Leg power data are presented in Appendix D. The peak power generated within the first 5 sec of the Wingate test was similar between both groups of divers for their respective non-dive day values. Post-dive testing revealed that the EOD group, who had done the swimming, had an average peak power reduction of 18%. In contrast, the SDV group, who conducted their dives with minimum leg exercise, had virtually no change in peak power.

By the end of the 30 sec Wingate test the EOD group had a post-dive leg power output approximately 12% lower than their pre-dive value, while the SDV divers had about 9% lower power output post-dive. Consequently, the total work achieved during the test was significantly lower post-dive in both groups.

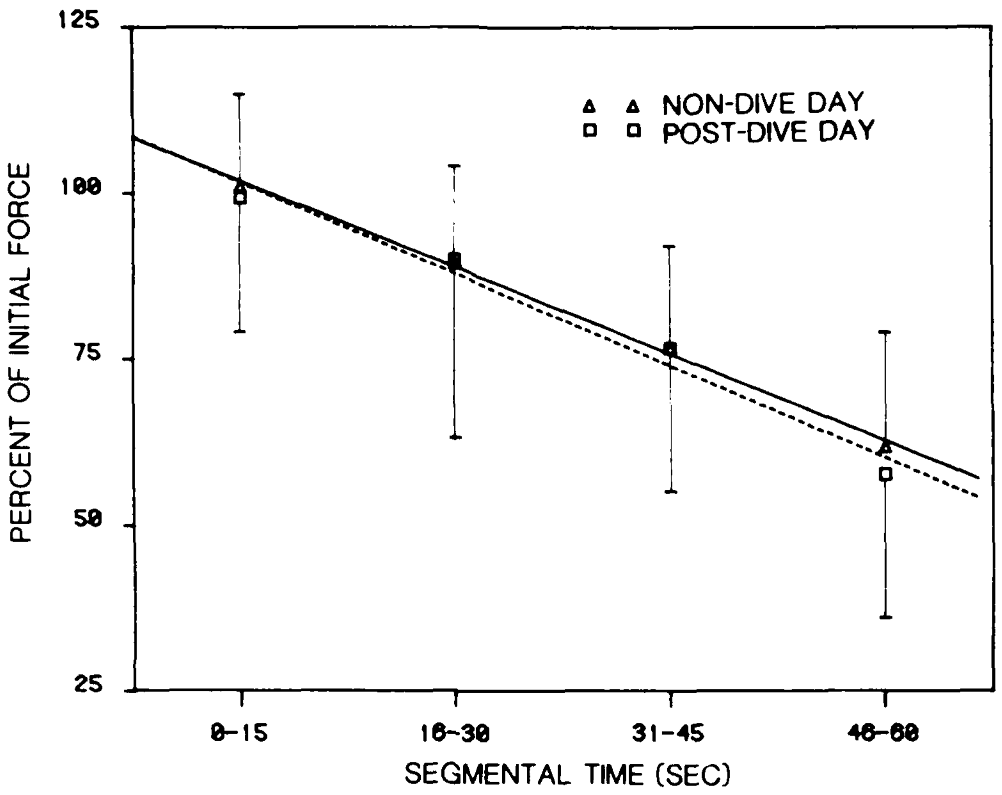

Fig. 1 Percent change in handgrip force for FOD divers. Each handgrip contraction value expressed as a percent of the first value for each diver. Symbols represent mean values (± SD) over each 15 sec segment of test for both right and left hand. Line through data points represents best-fit linear regression.

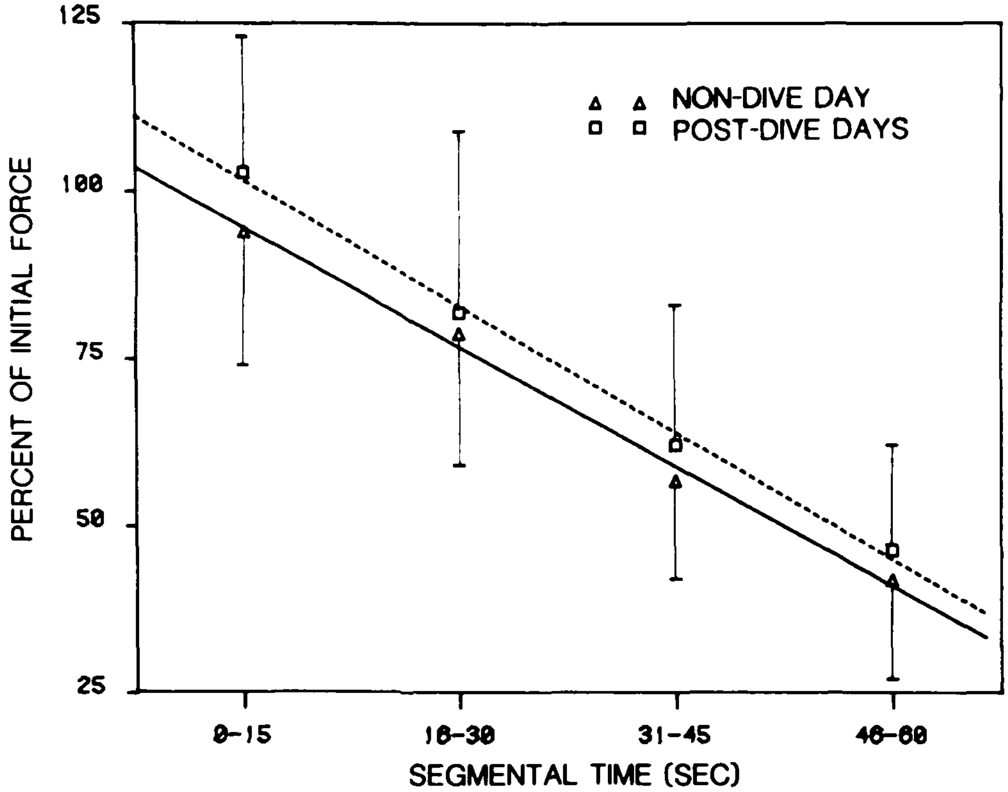

Fig. 2 Percent change in handgrip force for SDV divers. Presentation of data is the same as in Fig. 1.

DISCUSSION

The results of this study indicate that thermally unprotected divers swimming in cool water (24 °C) will have a relatively greater rate of heat loss than less active divers wearing wet suits in cold water (2 °C). This finding can be explained in several ways. Obviously, the wet suit provided thermal insulation to the SDV diver, while the EOD diver's body was unprotected.

A second explanation of the thermal findings relates to the type of work done by each diving group. The EOD divers were performing leg work, and no doubt the blood flow to the leg was increased as a result of the exercise, thereby providing a larger avenue for heat loss. The SDV divers were sitting in their vehicle for most of the dive, and therefore were performing minimal leg exercise. Consequently, the cold induced vasoconstriction in these divers would minimize heat loss through the legs. This explanation agrees with a previous study (11) that measured greater regional heat losses during moderate leg exercise in 18 and 30 °C water when compared to resting conditions. No change was observed in core temperature in that study, and is consonant with the present findings of no significant change in rectal temperature for either dive group.

Handgrip strength was reduced post-dive in the EOD group, a finding consistent with another of our open water studies (4) and that obtained in a laboratory setting (5). Such reductions in maximal strength may relate to cooling effects on reducing the velocity of muscle contraction or alterations in muscle fiber recruitment needed for maximal effort (8,9). The absence of significant post-dive changes in the SDV divers may be due to the small sample size of this group, or to less muscle cooling in these subjects who wore wet suits and performed some intermittent forearm exercise in the operation of the SDV.

The rate of decline in handgrip force was similar between non-dive and diving days for both groups. Over the course of 60 sec the ischemic handgrip test

reflects both the amount of glycogen in the muscle, as well as the intrinsic rate of glycogen breakdown (8). The similarity in declines of force with time therefore indicates that neither underwater exposure substantially alters the pattern of forearm muscle glycogenolysis.

The lower peak leg power generated post-dive in the EOD group may represent a relative degree of fatigue since this group was performing leg work during the dive. It is unlikely that glycogen depletion was a significant factor in this reduced power occurring within 5 sec of the start of the anaerobic test. This time frame is not heavily dependent on metabolic turnover of substrate for muscle contraction (9,10).

Initial muscle contractions rely on use of intrinsic high energy phosphate compounds. It would appear that the scuba swim, perhaps in conjunction with greater total body heat loss, represents a subtle form of fatigue that diminishes the contribution of muscle phosphate stores needed at the start of high intensity leg exercise. The SDV divers, spared the leg exercise, may have been able to mobilize more of these high energy stores and thereby generate maximum leg power. Detailed laboratory studies would be required to address this important issue.

Although the SDV divers were able to generate post-dive peak leg power values similar to control conditions, they were unable to sustain power at a similar pre-dive level over the remainder of the 30 sec Wingate test. In this respect the result was qualitatively similar to that obtained with the EOD group who had exercised their leg muscles prior to the post-dive test. Unfortunately, the small number of SDV divers precluded a meaningful comparison with results obtained in the EOD group. Qualitative inspection of the Wingate data infers that the post-dive decrement in total work was greater for the EOD divers than for the SDV divers. The difference between the EOD group's decrement and that of the SDV divers would estimate the loss in total work due to prior exercise, while the actual post-dive

decrement obtained with the SDV data would reflect the loss due to thermal effects.

In summary, the findings of this study have several important bearings on operational diving. Firstly, dives in relatively comfortable water without passive protection may result in a greater rate of body heat loss than dives conducted in colder water wearing a wet suit. Secondly, muscles not used extensively during a dive may have reduced maximal force values due to muscle cooling. However, post-dive fatigue rates in these muscles may not be influenced greatly by exposure to cold water. Finally, work performed by muscles groups during a dive may result in reduced peak power in the post-dive period, even though the exercise did not produce any noticeable fatigue. The balance between muscle power and fatigue versus mission specific goals must be considered in terms of water temperature and the nature of the effort required to reach the objective.

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APPENDIX A

PHYSICAL CHARACTERISTICS OF SUBJECTS

GROUP	AGE (yrs)	HEIGHT (cm)	WEIGHT (kg)	% BODY FAT*
EOD DIVERS (n=26)	28 ± 4	178 ± 6	83 ± 8	20 ± 3
SDV DIVERS (n=5)	26 ± 5	182 ± 5	88 ±14	20 ± 6

* % body fat obtained from 4 skinfold thicknesses.
All values are mean ± SD

APPENDIX B

CHANGES IN BODY HEAT

GROUP	CHANGES IN TEMPERATURE Rectal (°C)	Forearm (°C)	Thigh (°C)	CHANGES IN BODY HEAT Net Loss (kcal)	Normalized Loss (kcal/kg/dive hr)
EOD DIVERS	-0.0	-3.9	-4.3	92	1.3
(n=26)	±0.2	±0.3	±0.2	± 9	±0.1
SDV DIVERS	-0.3	-4.2	-6.5	147	0.9*
(n=5)	±0.2	±0.5	±1.1	± 20	±0.1

values are mean ± SE

Negative values for changes in temperature indicate lower post-dive values.

* $p<0.05$ from EOD divers by use of unpaired t-test.

APPENDIX C

HANDGRIP FORCE (kg) BEFORE and AFTER DIVING

GROUP	HAND	SEGMENTAL 15 sec AVERAGES 0-15	16-30	31-45	46-60
EOD non-dive (n=26)	RIGHT	48 ± 2	41 ± 2	37 ± 2	29 ± 3
	LEFT	49 ± 3	44 ± 2	37 ± 3	31 ± 3
EOD post-dive*	RIGHT	35 ± 2	31 ± 2	27 ± 2	20 ± 1
	LEFT	31 ± 2	27 ± 2	23 ± 2	17 ± 1
SDV non-dive (n=5)	RIGHT	30 ± 6	25 ± 6	17 ± 3	13 ± 3
	LEFT	33 ± 7	28 ± 5	20 ± 4	13 ± 3
SDV post-dives	RIGHT	35 ± 6	29 ± 4	20 ± 4	16 ± 4
	LEFT	44 ± 5	33 ± 4	26 ± 2	16 ± 3

values are mean ± SE

* All values with $p<0.05$ compared to corresponding non-dive values by paired t-test with Bonferoni correction.

APPENDIX D

WINGATE TEST LEG POWER RESULTS

GROUP	peak power at 5 sec (watt)	power at 30 sec (watt)	total work (kJ)
EOD non-dive day (n=26)	974 ± 31	458 ± 12	17.06 ± 0.54
EOD post-dive	798* ± 20	403* ± 11	14.61* ± 0.41
SDV non-dive day (n=5)	884 ±100	340 ± 27	13.77 ± 1.39
SDV post-dives	862 ± 63	311* ± 18	12.54* ± 0.67

values are mean ± SE
* $p<0.05$ from non-dive value by paired t-test with Boneferoni correction.

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